State of California
The Resources Agency
Department of Water Resources

SP-G2: EFFECTS OF PROJECT OPERATIONS ON GEOMORPHIC PROCESSES DOWNSTREAM OF OROVILLE DAM

TASK 6 – CHANNEL MEANDERS AND BANK EROSION MONITORING

Oroville Facilities Relicensing
FERC Project No. 2100

JULY 2004

ARNOLD SCHWARZENEGGER
Governor
State of California

MIKE CHRISMAN
Secretary for Resources
The Resources Agency

LESTER A. SNOW
Director
Department of Water Resources

State of California
The Resources Agency
Department of Water Resources

SP-G2: EFFECTS OF PROJECT OPERATIONS ON GEOMORPHIC PROCESSES DOWNSTREAM OF OROVILLE DAM

TASK 6 – CHANNEL MEANDERS AND BANK EROSION MONITORING

Oroville Facilities Relicensing
FERC Project No. 2100

This report was prepared under the direction of

Koll Buer.. Senior Engineering Geologist, DWR

by

Bruce Ross.. Engineering Geologist, Range D, DWR
Dave Forwalter.. Engineering Geologist, Range D, DWR

Assisted by

Bill Brewster .... Engineering Geologist, Range D, DWR
Tanya Meeth .... Engineering Geologist, Range D, DWR

And

Glen Gordon.. Engineering Geologist, Range C, DWR
Clint Andreasen..Student Assistant, DWR
Eric Willard ....Student Assistant, DWR

REPORT SUMMARY

The construction of Oroville Dam has altered the hydraulic, geomorphic, and sediment transport regimes of the Feather River. The Study Plan G2 reports are designed to identify and evaluate ongoing effects of altered downstream hydrology and sediment retention in Lake Oroville on channel morphology and sediment transport in the Lower Feather River. Specifically, the reports address the following components:

1. Determine sediment conditions and sediment transport requirements.
2. Evaluate sediment sources (including tributaries) and conditions.
3. Map major sediment deposits.
4. Evaluate stream channel stability.
5. Evaluate project-affected sediment regimes.
6. Evaluate timing, magnitude, and duration of project-affected flows in relation to geomorphic effects.
7. Determine the effect of the project on fluvial geomorphologic features.
8. Evaluate erosional effects on farmland (private and public trust resources).

Results from these components will be used to identify limiting factors (impacts associated with biological effects) and develop a comprehensive sediment management plan for the purposes of protection, mitigation and enhancement measures to improve river form and function in the Feather River. The study results will also be used by other studies to help assess the Oroville Facilities ongoing effects on downstream water quality, aquatic and riparian resources, and protection of private lands and public trust resources.

The study plan is organized into individual tasks and sub-tasks that are addressed in separate reports because of the amount and complexity of the data. These are:

- Task 1.1 - obtain, review, and summarize existing resource data and references;
- Task 1.2 – prepare a general description of the lower Feather River and watershed, including mesohabitat typing and large woody debris characterization;
- Task 2 - map and characterize spawning riffles;
- Task 3 - evaluate changes to the channel morphology by re-establishing historic cross-section surveys and photo points;
- Task 5 - determine project effects on river hydraulic and geomorphic parameters;

- Task 6 - evaluate historic channel meandering; establish bank erosion monitoring sites
- Task 7 - model sediment transport and channel hydraulics; make predictions
- Tasks 8 - summarize other task reports; make recommendations to assess current channel characteristics and to monitor selected cross-sections for significant changes to those characteristics

This task report fulfills the requirements for "Task 6 – Channel Meanders and Bank Erosion Monitoring". The report presents the sub-tasks, methodology, and results completed to date. Results from this Task report are also summarized in "Task 5 – Dam Effects on Channel Hydraulics and Geomorphology".

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

This report evaluates Feather River geomorphic changes resulting from the construction of Oroville Dam. The study reach begins at the Fish Barrier Dam near Oroville and extends to the mouth of the Feather River at Verona, a river distance of about 70 miles. The report identifies the hydraulic, geomorphic, and sediment transport changes that have occurred. The effect of these changes on salmonid spawning riffles, flooding, riparian vegetation, riparian habitat, and river habitat was also considered.

Changes in sediment transport will be evaluated by use of a sediment transport model. This model will also be used to predict changes in sediment transport and channel meandering resulting from various proposed flow regimes. Based on the results of the study, we will identify needs for protection, mitigation or enhancement activities. The study results will also be used by other studies to help assess and predict the Oroville Facilities ongoing effects over the next 25 and 50 years on downstream water quality, aquatic and riparian resources, and protection of private lands and public trust resources.

The *Task 6- Channel Meanders and Bank Erosion Monitoring* is one of eight reports that fulfill the scope of study plan G2.

1.1 BACKGROUND INFORMATION

The Feather River is an important resource for salmonid spawning habitat in California, second only to the Sacramento River. The completion of Oroville Dam in 1967 reduced this habitat by blocking access to upstream reaches. This includes 25 miles to Miocene Dam on the West Branch, 21 miles to Poe Powerhouse on the North Fork, 19 miles to Curtain Falls on the Middle Fork, and 8 miles to Ponderosa Dam on the South Fork. This loss of spawning habitat was mitigated by the Feather River Fish Hatchery. The Hatchery provides an artificial spawning and rearing facility for Chinook salmon, and steelhead.

Oroville Dam also affects hydrology and sediment transport characteristics, altering the movement of water, sediment, and woody debris in the river. The primary function of the dam is to store winter and spring runoff for release into the river as necessary for project purposes. This results in an altered hydrologic regime that includes changes to the yearly, monthly, and daily stream flow distributions; bankfull discharge, flow exceedance, peak flow, and other hydraulic characteristics.

It also means that the reservoir along with other hydroelectric projects on the Feather River captures almost all of the sediment eroded from the upper Feather River watershed. This changes patterns of sediment transport and deposition, scour, mobilization of sediment, and levels of turbidity. These changes can result in the coarsening of spawning gravel on riffles, which in turn may adversely affect salmon and steelhead.

These changes to the river hydrology and sedimentation patterns will in turn alter the channel morphology. These can include changes to the channel shape, meandering, and capacity.

All of these potential impacts may extend downriver from Oroville Dam to the junction with the Sacramento River or beyond. These are further complicated by a long history of a variety of land uses along the Feather River including hydraulic mining, gravel mining, gold dredging, timber harvesting, water diversions, and urbanization.

1.1.1 Study Area

The Lower Feather River flows about 72 miles from Oroville Dam to the Sacramento River at Verona. The river flows past distinctive geographic and geomorphic features. These are shown in Table 1.1-1.

Table 1.1-1. River Miles, Valley Miles and Related Geographic Features of the Feather River

RIVER MILE (1997 USACE)	RIVER MILE (USGS)	VALLEY MILE	GEOGRAPHIC FEATURE
71.5			Oroville Dam
67.2	67.8		Thermalito Diversion Dam
66.5	67.2		Fish Barrier Dam
66.3	67.0		Table Mountain Bridge
65.0	65.6		Highway 70 Bridge
58.7	59.0		Confluence with Thermalito Afterbay Outflow
50.6	50.8		Gridley Bridge
44.3	44.0		Confluence with Honcut Creek
42.5	42.3		Live Oak
27.9	28.5	24.9	Yuba City and Marysville
27.1	27.5	24.4	Confluence with Yuba River
N/A	25.4	22.6	Upstream End of State Cutoff (1909)
N/A	22.5	20	Downstream End of State Cutoff (1909)
N/A	19.5	17.4	Abbot Lake
N/A	18.8	16.7	Star Bend

RIVER MILE (1997 USACE)	RIVER MILE (USGS)	VALLEY MILE	GEOGRAPHIC FEATURE
N/A	17.0	15.7	O'Conner Lakes
N/A	13.0	12.3	Lake of the Woods
N/A	12.5	11.6	Confluence with Bear River
N/A	9.6	9.1	Town of Nicolaus
N/A	9.3	8.9	99 Bridge (Garden Highway)
N/A	8.2	8	Upstream End of State Cutoff (post-1911)
N/A	7.5	7.3	Upstream End Sutter Bypass; Downstream End State Cutoff (post-1911)
0.0	0.0	0	Verona, Confluence with Sacramento River

More effort was spent on the 39-mile reach from the Fish Barrier Dam to Yuba City (Figure 1). Below Yuba City, the Yuba and Bear Rivers join the Feather, and the overall effect of Oroville Dam is greatly reduced. The study boundary extends laterally to the edge of the 100-year floodplain as defined by the USACE (1997).

The study reach is further divided into four subreaches based on differences in the hydrologic flow regime (Figure 1.1-1). The first (the Low Flow Reach) is the 8-mile stretch between the Fish Barrier Dam and the Thermalito Afterbay outflow. The second is the 39-mile reach between the Afterbay outflow and the Yuba River. The third is the 15 miles from the confluence of the Yuba River to the confluence of the Bear. The fourth, about 12 miles long, begins at the confluence with the Bear and ends at the confluence of the Feather and the Sacramento River at Verona.

Most of the SP-G2 study effort was on the salmon spawning reach between the Fish Barrier Dam and Honcut Creek. The activities included in this reach are: FLUVIAL-12 model, sediment sampling, permeability, dissolved oxygen, and temperature measurements. Below Honcut Creek, geomorphic and mesohabitat typing was done, including bank erosion, bank composition, habitat, geology, soils, and woody debris.

1.1.2 Description

The Feather River watershed is mainly in the northern Sierra Nevada geomorphic province. The river drains the western slope of the Sierra Nevada and is tributary to the Sacramento River. Some of the headwaters also lie within the Basin and Range geomorphic province, containing both steep forested mountains and large intermountain valleys. The climate is Mediterranean, with mostly dry summers and wet winters. Annual precipitation ranges from 75 inches in the upper watershed to 30 inches in the lower watershed near Oroville Dam.

The Feather River is underlain by resistant metamorphic, volcanic, and plutonic rocks in the 4-mile reach downriver of Oroville Dam to the Fish Diversion Dam. It is incised into these rocks, forming steep canyon walls.

Below the town of Oroville, the Feather River emerges from the Sierra Nevada into the foothills of the Sacramento Valley. At about three quarters of a mile below the Diversion Dam, at the first major spawning riffle, bedrock is still exposed in the channel. Below Bedrock Park, the river begins to flow in an alluvial channel incised into dissected older alluvial uplands.

The Oroville Wildlife Area, consisting of dredger tailings and borrow pits, occurs from a few miles below Oroville to a few miles above Gridley. Below the dredger tailings, the river meanders through hydraulic mining debris, floodplain deposits, and older terrace deposits.

1.1.3 River Access

The river is accessible by vehicle through the Oroville Wildlife Area and public parks. Numerous public boat ramps are also available. Jet boats can often be used in the High Flow Reach and sometimes in the Low Flow Reach dependent on flow. Seasonal variations in flow can make some riffles difficult or impossible to navigate and submerged snags can be an additional hazard.

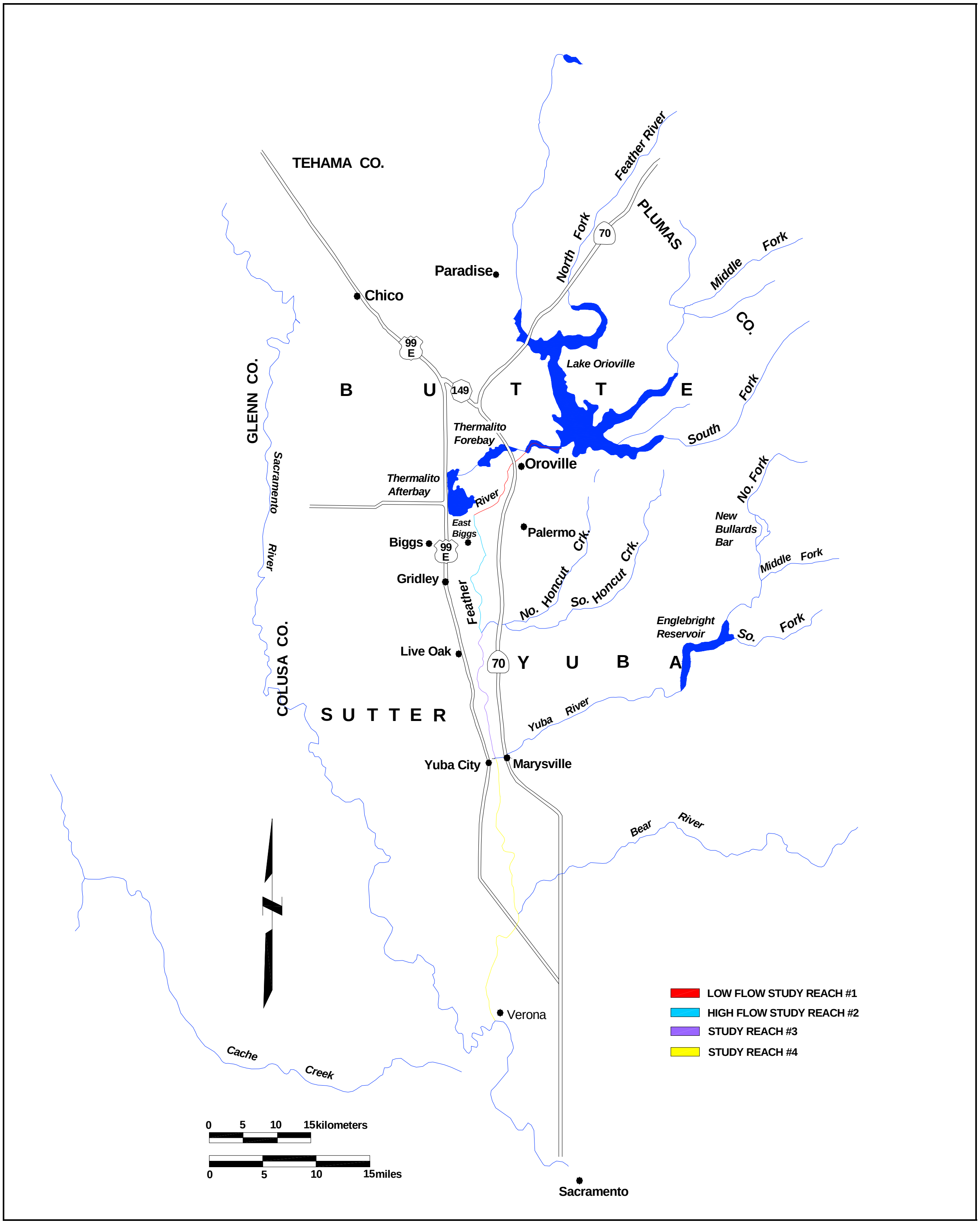

Figure 1.1-1. SP-G2 Geomorphic Study Area and Subreaches, Lake Oroville to Yuba City

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. Figure 1.1-2 shows an overview of these facilities and the FERC Project boundary. Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (maf) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

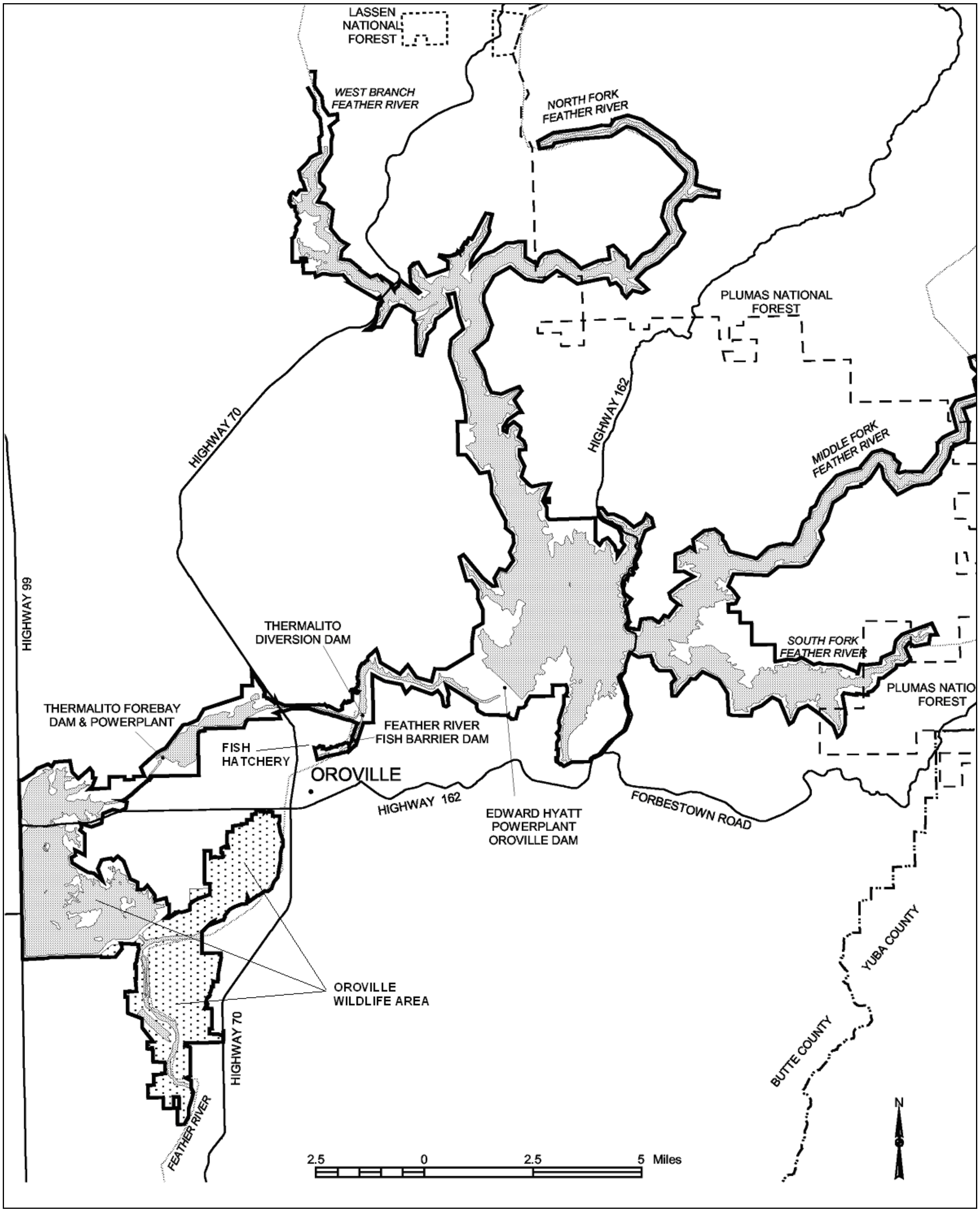

Figure 1.1-2. Overview of FERC Project No. 2100 Facilities

Thermalito Diversion Dam four miles downstream of the Oroville Dam creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000-acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning are conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrologic conditions are drier than expected or water requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG entitled, "Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife," sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the Lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for objectives, April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead trout and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to control water temperature at Feather River mile 61.6 (Robinson’s Riffle in the low-flow channel) from June 1 through September 30. This measure requires water temperatures less than or equal to 65°F on a daily average. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) af are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake

Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

2.1 PURPOSE AND SCOPE

A naturally functioning channel in dynamic equilibrium is capable of transporting the water and sediment delivered to it without significantly changing its geometry, streambed composition, or gradient through time. The flow conditions that promote this stability can be described as geomorphically significant flows (bankfull). These flows do the majority of the sediment transport and are considered most responsible for channel form. A natural flow regime typically includes flow ranges responsible for in-channel clearing and overbank flows to support riparian vegetation, along with channel-forming flows.

The altered sediment routing and hydrology caused by the Oroville Facilities have affected river morphology. There is a need to understand these relationships and identify potential protection, mitigation and enhancement measures.

The SP-G2 Task 6 geomorphic report compares historic and current conditions to help identify ongoing project effects to channel meander and bank erosion in the downstream reach defined in this study. This information will be used by other studies to help assess the project's effects on plant, fish, animal, and riparian resources. These data, together with other study results, will provide boundary conditions for assessing potential management actions.

Project -related structures and operations alter flow regimes, which can impact the occurrence of geomorphically significant flows. The Task 6 report addresses potential adverse effects from these flows including changes in the rate of channel meander and bank erosion.

3.0 STUDY OBJECTIVE(S)

3.1 APPLICATION OF STUDY INFORMATION

The objective is to determine the ongoing effects of altered downstream hydrology and sediment retention in Lake Oroville on channel morphology and sediment transport below Lake Oroville.

The study will determine the ongoing Oroville Project effects on river flows and morphology downstream of Oroville Dam. Specifically, the study will address the following components:

1. Determine sediment conditions and sediment transport requirements.
2. Evaluate sediment sources (including tributaries) and conditions.
3. Map major sediment deposits.
4. Evaluate stream channel stability.
5. Evaluate project-affected sediment regimes.
6. Evaluate timing, magnitude, and duration of project-affected flows in relation to geomorphic effects.
7. Determine the effect of the project on fluvial geomorphologic features.
8. Evaluate erosional effects on farmland and public trust resources.

This Task 6 report addresses changes to the lower Feather River channel meander and bank erosion resulting from the operation of Oroville Dam.

Study results will be used to identify limiting factors and biological effects. The information will be used to develop a comprehensive sediment and flow regime management plan to improve form and function in the Feather River. The study results will also be used by other studies to help assess the Oroville Facilities ongoing effects on downstream water quality, aquatic and riparian resources, and protection of private lands and public trust resources.

3.2 OTHER STUDIES

Studies related to spawning gravel quantity and quality began before construction of Oroville Dam. DWR (1965) studied pre-dam channel characteristics, and then DWR (1969) and the USGS (1972) conducted studies to document channel changes. In 1977 DFG studied the interim impacts of the dam on salmonid escapement. In 1978 the USGS completed a study to evaluate sediment transport and discharge.

DWR (1982) prepared the Feather River Spawning Gravel Baseline Study to determine post dam spawning gravel conditions. The report presented spawning gravel sampling results and identified factors resulting in loss of spawning gravel quality. These include the lack of gravel recruitment from areas above Oroville Dam and the effect of scouring flood flows. A follow-up habitat restoration project was conducted by DWR and DFG in 1982 at the riffle sites adjacent to the Hatchery. These sites were identified in the baseline study as having undergone significant post-dam degradation.

4.0 STUDY ORGANIZATION

The construction of Oroville Dam has altered the hydraulic, geomorphic, and sediment transport regimes of the Feather River. The SP-G2 reports are designed to identify and evaluate ongoing effects of altered downstream hydrology and sediment retention in Lake Oroville on channel morphology and sediment transport in the Lower Feather River. Specifically, the reports address the following components:

1. Determine sediment conditions and sediment transport requirements.
2. Evaluate sediment sources (including tributaries) and conditions.
3. Map major sediment deposits.
4. Evaluate stream channel stability.
5. Evaluate project-affected sediment regimes.
6. Evaluate timing, magnitude, and duration of project-affected flows in relation to geomorphic effects.
7. Determine the effect of the project on fluvial geomorphologic features.
8. Evaluate erosional effects on farmland and public trust resources.

4.1 STUDY DESIGN

It is widely recognized that dams affect downstream reaches of the river system in significant ways. These reaches "experience departures from natural conditions by changes in their hydrology (water yield, flows, low flows, timing of discharge events), sedimentology (sediment discharge, size distribution of sediment), geomorphology (channel and floodplain forms and processes) and biotic systems (riparian vegetation, fish and wildlife)" (Graf, 1996). These characteristics interact so as to tend to a state of dynamic equilibrium. This means that altering any of the characteristics will disrupt the equilibrium, forcing readjustment of the other variables toward a new altered state of equilibrium. This Task Report 6 concentrates on the geomorphic changes to the channel; specifically rates of channel meander and bank erosion.

This report fulfills the requirements for Task 6 to identify and quantify changes in channel meander and bank erosion along the lower Feather River resulting from the operation of Oroville Dam. It also examines changes in channel sinuoisity and radii of curvature. Dam effects on other channel geomorphic characteristics (depth, width, hydraulic radius, roughness, gradient, pool-riffle-run ratio), hydraulics, and sedimentology are examined and presented as part of "Task 5 – Dam Effects on Channel Hydraulics, Geomorphology and Sedimentation".

4.2 HOW AND WHERE THE STUDIES WERE CONDUCTED

The first half of the Task 6 report focuses on determining the effect of project operations on channel meander and bank erosion. This was done by using geologic maps in conjunction with aerial photo interpretation to identify structural controls on river erosion and plan form. These aerial photos and old survey maps were used to establish the location of historic river channels and used to establish the extents of the meander belt. Pre- and post-dam channel locations, water's edge, and cut banks were then delineated on the atlas using AutoCad drafting and Arc-View GIS software. Ongoing impacts of the dam were evaluated by comparing pre- and post dam bank erosion and channel migration rates. Figures, graphs, and charts were prepared and presented showing the changes.

The second half of the Task 6 report uses the results from the first half to identify, locate, survey and monitor specific bank erosion locations in both the Low- and High-flow reaches. Available past cross-sectional data intersecting significant erosion sites was also compared to those surveyed in Task 3. This further evaluates erosional changes to the channel caused by the dam. Finally recommendations for the number, extent, and timing for monitoring of bank erosion sites are presented.

5.0 MEANDER BELT DYNAMICS

5.1 METHODOLOGY AND RESULTS

Both aggradational and degradational processes operate simultaneously in a normal river system. Bank erosion occurs along the outside bends, resulting from high flow velocities impinging on erodible bank deposits. Coarse sediment deposition in the form of lateral accretion occurs at point bars on the inside of the bends. Vertical accretion of fine sediment occurs during floods in overbank areas. A stream is in balance if the deposition and erosion are equal. The river is aggradational if deposition is greater than erosion, and degradational if erosion is greater deposition.

The lower Feather River, prior to 1855, was a meandering stream, believed to be similar to the present Sacramento River between Red Bluff and Colusa (WET, 1990). As a meandering stream, the river eroded its banks and deposited sand and gravel on point bars. Bank erosion and river movement was more pronounced. The width of the river and its floodplain remained constant over time.

The massive influx of hydraulic mining debris buried the natural channel and floodplain. As much as 20 feet of deposition was reported in Marysville. Much of the deposition occurred in the channel and adjacent overflow area. The result of this is that the river is perched on these deposits above the surrounding floodplain, aggravating flooding during high flow events. Subsequent degradation and down-cutting through these clay-rich and cohesive deposits resulted in erosion resistant banks and a more stable river system.

The Feather River was, and still is, constrained to a relatively narrow meander belt by erosion resistant terrace deposits of the Modesto and Riverbank formations. The meander belt width varies from less than one mile to more than three miles.

5.1.1 Methodology

Aerial photos and old survey maps were used to establish the location of historic river channels. The dates of the maps and aerial photos used included 1909, 1956, 1967, 1986, 1997 and 2001. The maps and photos were scanned and rectified and were used to establish the extents of the meander belt (if any). Geologic maps were used with aerial photo interpretation to identify structural controls on river erosion and plan form.”

The procedure followed included collecting existing survey, topographic, and photographic data, and plotting channel locations for the years available on the atlas and the GIS. Changes in channel location, islands, multiple channel areas, levees, and riprap were delineated. Ongoing impacts of the dam were assessed by comparing pre- and post dam bank erosion and channel migration rates, island and multiple channel formation rates, gravel bars, riffles, channel width, gradient, and other geomorphic characteristics.

5.1.2 Meander Belt

A meander belt is defined as the area in which a meandering river shifts its channel through time. It is delineated by lines drawn tangentially to the extreme limits of all fully developed meanders. The historic meander belt is defined as the area enclosed by all Holocene (last 10,000 years) meander deposits. The 100-year meander belt is also commonly defined because of the general availability of surveys, maps, and photos for that time period, allowing for accurate delineation of the boundaries.

The meander belt consists of Recent alluvium (Qa) and stream channel deposits (Qsc). The alluvium is older, but both consist of river deposits, including floodplain deposits, point bar deposits, channel fill, oxbow lake deposits, tributary delta deposits, and others. The deposits range in size from clay, silt, and sand to gravel, cobbles, and boulders. The coarse deposits predominate near Oroville and the fine deposits predominate from Gridley downstream. The historic meander belt is shown on the Aerial Photo Atlas and Figures 5.1-1, 5.1-2, 5.1-3, and 5.1-4. The Historic meander belt is interpreted from the distribution of geologic units, topographic data, and maps and aerial photos dating back to 1909. The Feather River Meander belt is more difficult to interpret than for most rivers because the deposition of a thick wedge of hydraulic mining debris in the late nineteenth century has obscured typical meander belt features such as oxbow lakes and meander scrolls.

The 100-year meander belt is also shown on Figures 5.1-1, 5.1-2, 5.1-3, and 5.1-4, and on the Oroville FERC GIS. The 100-year meander belt is a compilation of the river channel locations from maps and aerial photography between 1909 and 2001. As shown on the figures the “1909 changes” are areas that filled in (including oxbow lakes and sloughs) or the channel migrated across between 1909 and 1967, and the “1967 changes_2” are areas that filled in or the river migrated across between 1967 and 2001. The “1967 changes are areas that eroded between 1909 and 1967, and the “2001 changes” are areas that eroded between 1967 and 2001. Taken together these channel changes show the extent of channel migration before and after dam construction.

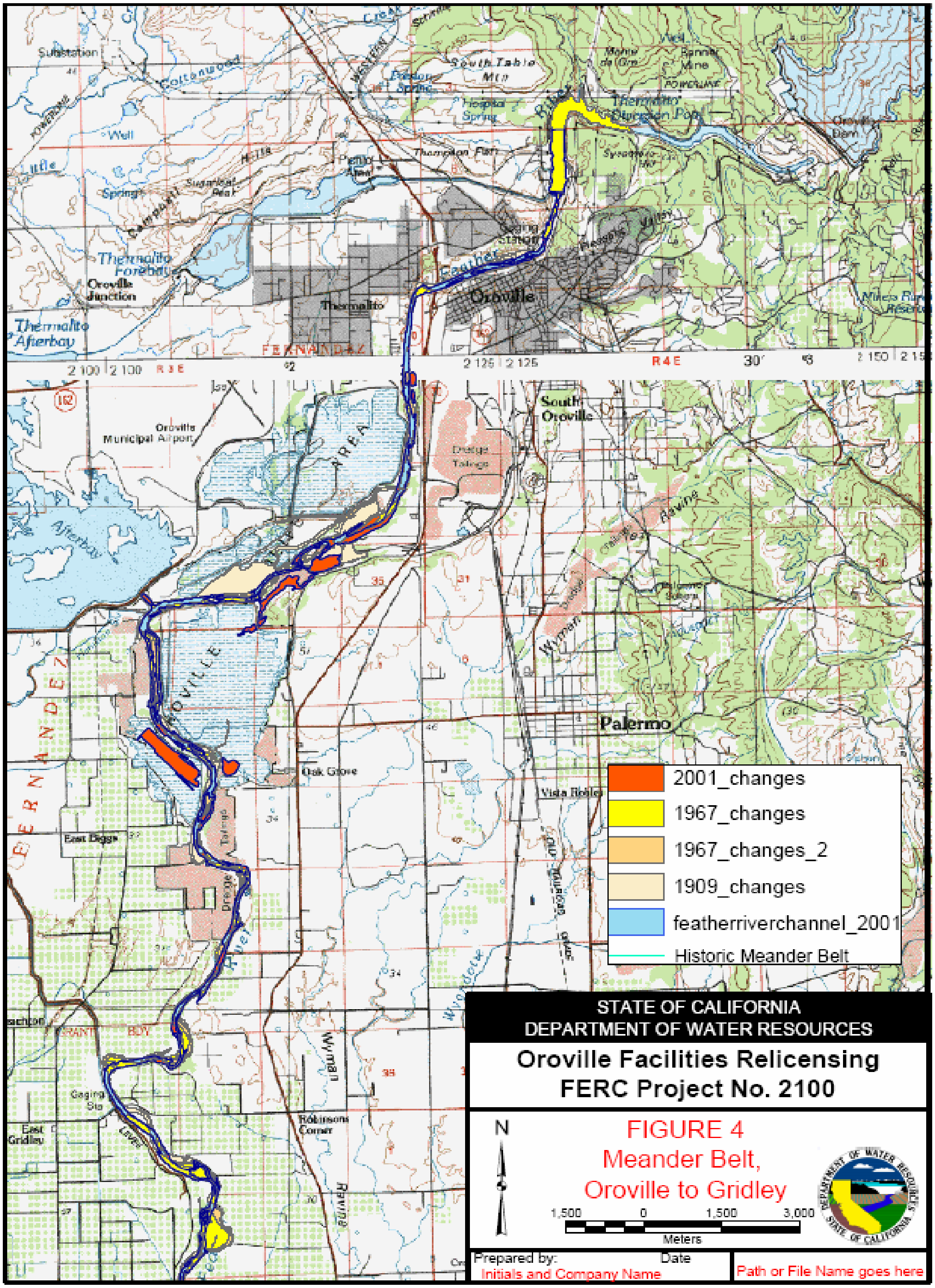

Figure 5.1-1. Meander Belt, Oroville to Gridley

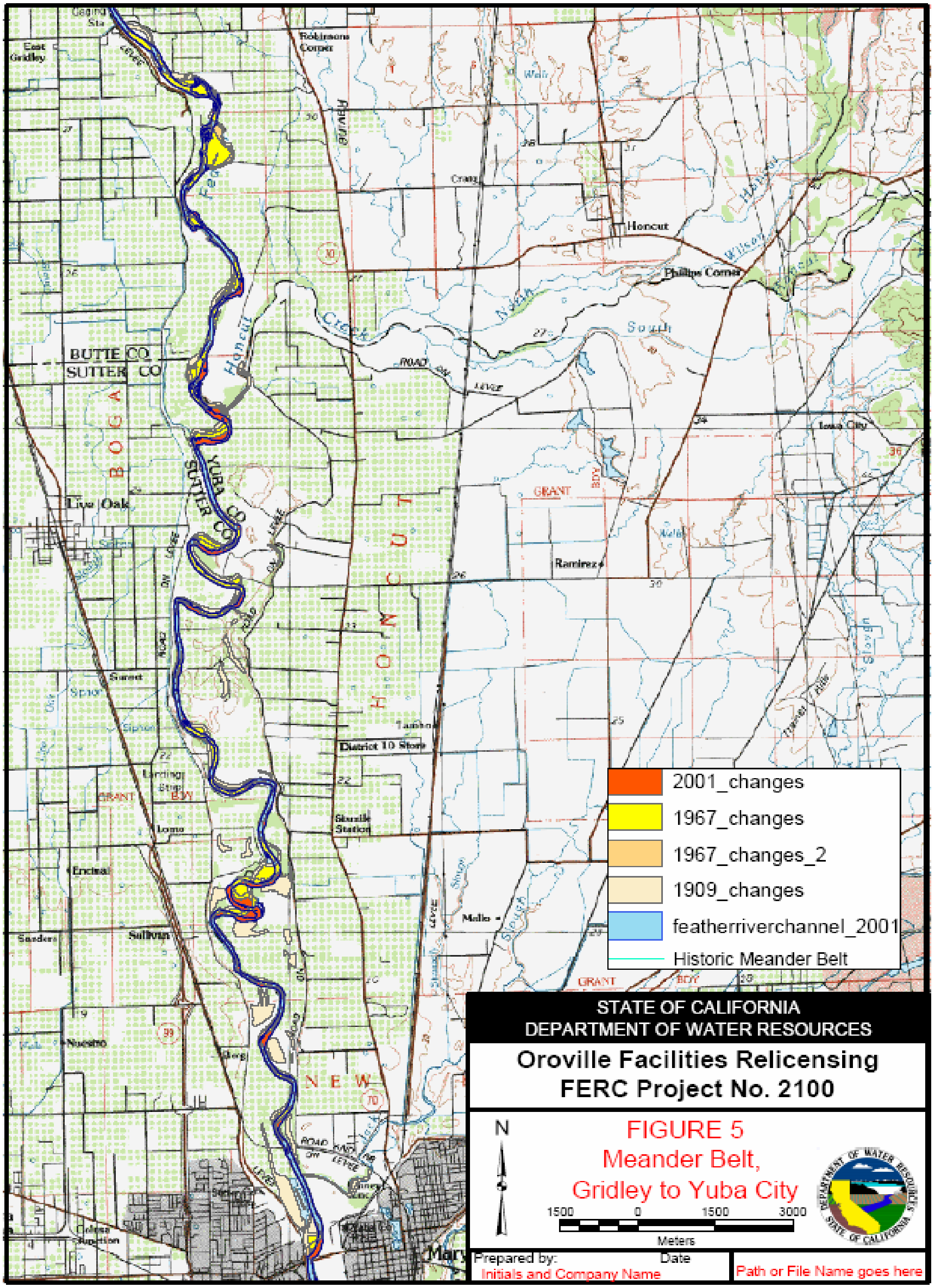

Figure 2.1-2. Meander Belt, Gridley to Yuba City

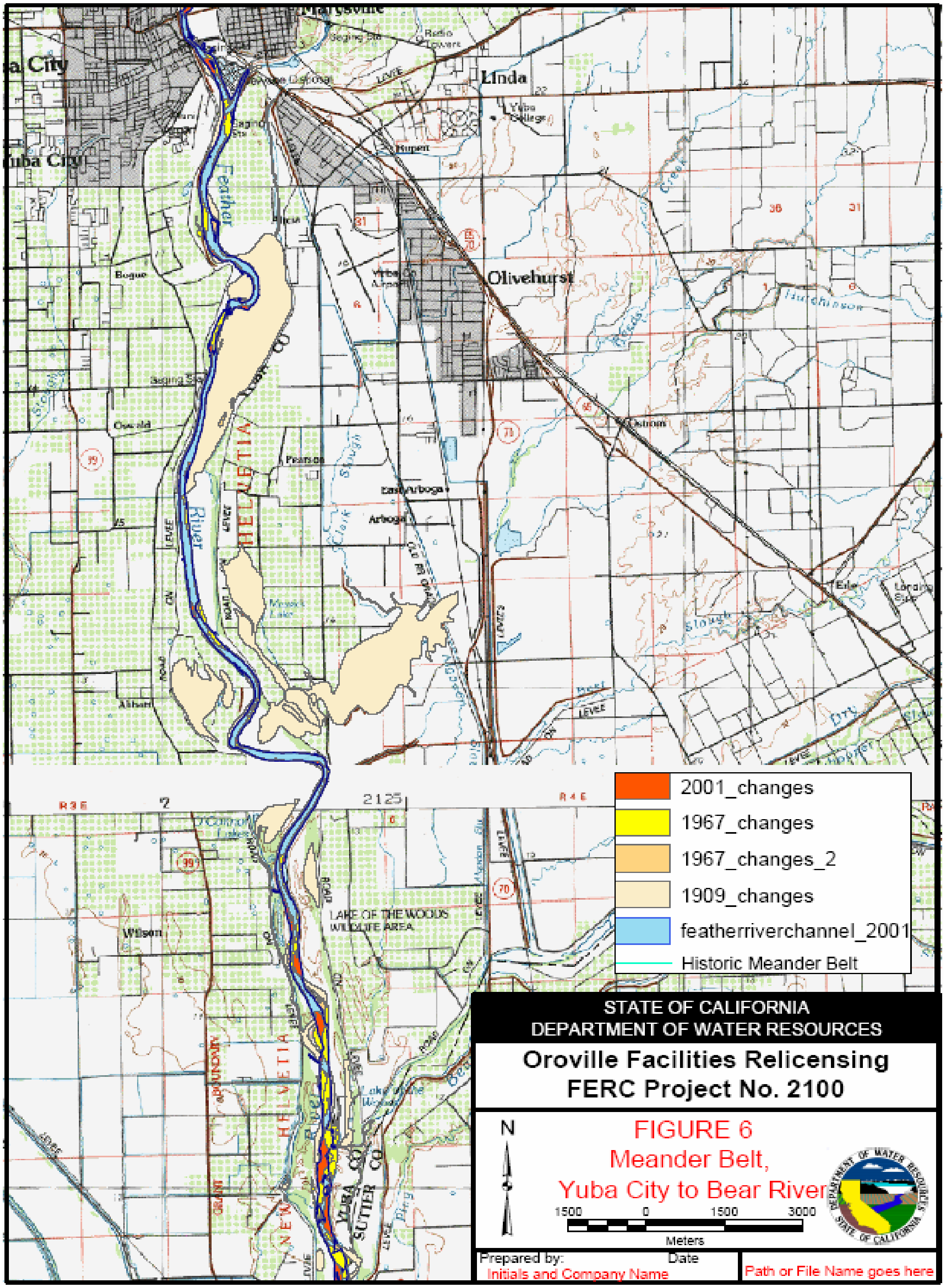

Figure 5.1-3. Meander Belt, Yuba City to Bear River

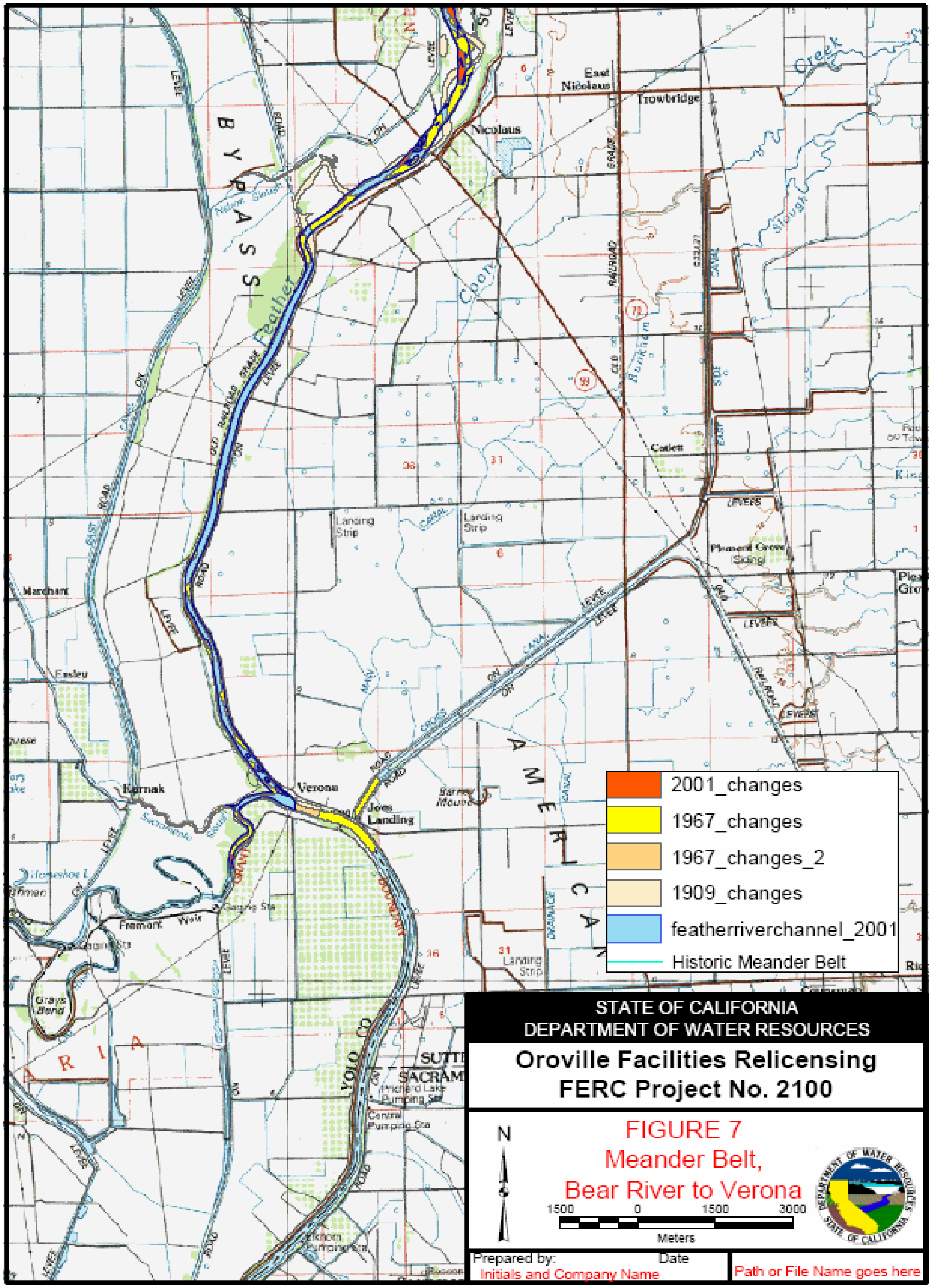
2001_changes
1967_changes
1967_changes_2
1909_changes
featherriverchannel_2001
Historic Meander Belt
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
FIGURE 7
Meander Belt,
Bear River to Verona
N
1500 0 1500 3000
Meters
Prepared by:
Initials and Company Name
Date
Path or File Name goes here
East Nicolaus
Trowbridge
Nicolaus
Feather
BYPASS
Verona
Karnak
Marchant
Catlett
Pleasant Grove
YOLO

Figure 5.1-4. Meander Belt, Bear River to Verona

5.1.3 Geologic Control

Geologic control of a meander belt occurs when geologic units that are resistant to erosion in some degree are present in the river banks or along the valley floor. Complete descriptions of the geologic units are provided in the Task 1.2 Report. The degree of resistance to erosion of the rock units providing geologic control can vary from essentially non-erodible consolidated bedrock to units with an increased clay content or slight consolidation that just slow erosion.

The Feather River banks from the fish barrier dam to the Feather River Hatchery, are composed of metamorphosed volcanic rocks of the upper Jurassic age Logtown Ridge Formation. This hard and highly erosion resistant bedrock results in a stable channel. Downstream of the Hatchery the valley begins to open up and the river has an alluvial bed and banks.

From the Fish Hatchery to just below the Highway 162 bridge, the meander belt is defined along the right side by tall cliffs underlain by Laguna Formation. On top of the cliffs are scattered exposures of the Red Bluff Formation. The Laguna Formation is rich in cohesive clay, and is erosion resistant and therefore constitutes geologic control. The river is directly against this cliff and is constrained from moving toward the west from just below the Highway 70 bridge to just below the Highway 162 bridge. There is a volcanic gravel unit at river level in the upper end of this stretch that has been mapped differently by different sources, but is resistant to erosion.

On the south/east side of the river at Oroville the margin of the meander belt is not clearly defined having been obscured by dredging and the development of the city of Oroville. The historic meander belt is assumed to cut across the west side of Oroville along the margins of the formerly dredged area. These deposits have not eroded since construction of Oroville Dam.

Below the Highway 162 bridge, the river opens into the Sacramento Valley. The left, or east, margin of the meander belt is composed of erosion resistant Lower Modesto Formation terrace deposits. The demarcation between the terrace deposits and the valley floor is a steep slope about 30 feet high. The right margin on the west side follows the edge between dredge tailings, composed of cobbles and gravel, coarse remnants of hydraulic mining debris, and older terrace deposits of the Modesto, Riverbank, and Laguna Formations.

Older terrace deposits, mostly Modesto but some Riverbank, constrain the meander belt all the way to the confluence with the Sacramento River. Between Gridley and Yuba City, the meander belt averages only about a mile wide between geologic control. In a few places in this reach, the river intersects the terrace deposits. In most places, the banks in this reach consist of alluvium, mostly sand and silt overlying clay and silt slickens.

5.1.4 Historic Changes in Channel Meander

DWR compiled pre- and post Oroville Dam meander lines. Pre-dam erosion and meandering was derived by comparing 1909 and 1967 topographic mapping and aerial photographs. Post dam was measured by comparing 1967 and 2001 aerial photographs. Bank erosion sites were identified by shifts in bank line, and the average amount of bank recession was calculated by dividing the acreage of bank movement by the number of years between bank lines. The sites selected by river mile and the area of bank line migration are shown in Appendix A, Table 1 for 1909-1967 and Table 2 for 1967-2001. The total acreage of change between 1909 and 1967 was 1,050 acres for a rate of 18.1 acres per year or an average of 2.26 sq. ft./ft./year. The total acreage of change between 1967 and 2001 was 460 acres for a rate of 13.5 acres per year or an average of 1.69 sq. ft./ft./year.

Overall the rate of channel migration for the Feather River is very low especially when compared to the Sacramento River between Chico and Colusa where the average rate of migration is 6.7 sq. ft./ft/year or Red Bluff to Chico with an average rate of 14.2 sq. ft./ft./year (DWR 1994). The Feather River has a relatively narrow meander belt and also is currently partially entrenched into the slickens deposits of hydraulic mining debris. The average rate of meander has decreased since the completion of Oroville Dam. The most likely reason for this reduction is the decrease in the frequency of channel forming flow events.

5.1.5 Historic Changes in Sinuosity and Radii of Curvature

Sinuosity is defined as the ratio of river length to down-valley length, and is an expression of the size and number of curves. Overall, the study reach has a sinuosity ratio of 1.29, between Oroville and Yuba City the sinuosity is 1.39, and from Yuba City to Verona the sinuosity is 1.16 as measured from topographic maps. This is considered low. Figures 5.1-1, 5.1-2, 5.1-3, and 5.1-4 show the sinuosity of the Oroville to Yuba City reach. Water Engineering and Technology (1990) calculated that the Yuba City to Verona reach has a sinuosity of 1.1 and had decreased in sinuosity in the last century. Most of the decrease occurred as a result of channel straightening between River Miles 7 and 14 that occurred prior to 1956. Some of the change is attributable to channel dredging at Nelson Bend in the 1920's. It is possible that the remainder of the change is also from dredging to straighten the channel during that time frame.

The combination of historical observations and present day channel sinuosity suggest that the Feather River was more sinuous prior to hydraulic mining than today (WET 1990). An indication of this is the meander features that are present on the 1909 Debris commission maps. The present-day sinuosity is not substantially different from that of the 1920's. Because of the entrenchment of the Feather River into hydraulic mining debris and the flood control functions of the Oroville Facilities, it is expected that the sinuosity will not change substantially in the next fifty years.

6.0 BANK COMPOSITION, EROSION AND MONITORING

6.1 METHODOLOGY AND RESULTS

In areas where bank erosion is occurring, monitoring sites were established to determine erosion rates and the nature of the material eroded. The eroding bank endpoints were marked using steel pipe set in concrete monuments. Banks were surveyed in November 2002, and in March 2004

For all identified transects, detailed field measurements included surveying the channel profile into the floodplain and abandoned floodplain (if present), identification of bankfull elevation, water surface slope, and the wetted perimeter at the time of measurement. Substrate material was documented (Wolman pebble count and laboratory grain size analysis), and bank slope was recorded for alluvial sections. An assessment of out-of-channel flow requirements for riparian vegetation/floodplain landforms was completed at approved transect locations. In addition, measurement of channel dimensions, indicators of sediment accumulation (V* or other sediment accumulation indicator), quantitative analysis of flows required to initiate motion (Shields criterion), and quantitative comparison of sediment supply and transport capacity (expressed in tons/day or equivalent) were analyzed at each site.

6.1.1 Bank Composition and Erodibility

The bank composition of the Feather River was classified and mapped according to the following recognizable units: Bedrock, Laguna Formation, Modesto Formation, slickens, dredge tailings, flood plain deposits, alluvial banks, and levees. The distribution of these bank types through the study reach is shown on Atlas B.

The bank composition was mapped by trained geologists boating along the river and reaching consensus on the bank composition. The bank composition was mapped on the 2001 1:7200 aerial photo atlas and transferred to the GIS system on the same base. The locations of rip-rapped banks were also noted during bank mapping. The bank composition classifications are as follows:

Bedrock - Bedrock was used to describe the Mesozoic bedrock, hard rock, in the upper reaches of the river, and occurred only from the diversion dam to Bedrock Park.

Laguna – Laguna deposits are yellowish brown to tan, silty clay that are firm and somewhat resistant to erosion. They most often occur as vertical banks at the outside of stable bends and commonly underlie Modesto deposits.

Modesto – Modesto deposits are brown to gray silt to clay that have a well developed soil horizon. They are stable where they overlie Laguna but are erodible where exposed at the waters edge. They commonly occur as steep to vertical banks.

Slickens – Slickens are the hydraulic mining debris deposits and are usually orangish, silt, clay, and sand, and can be massive to bedded. They occur as steep banks on stable stretches of the river and are somewhat resistant to erosion. The river has entrenched into these deposits.

Tailings – Tailings are the dredge tailings from gold mining activities. They form steep banks of cobble and gravel.

Flood Plain - Flood plain deposits are massive to slightly bedded silt, sand, and clay exhibiting no soil structure. The deposits are brown to gray, unconsolidated and occur as steep banks commonly being eroded on the outside of bends.

Alluvial - Alluvial banks are shallow, gently sloping banks exhibiting recent depositional features such as open gravel or sand banks and generally occur on the insides of bends or at riffles. Banks consisting of alluvial bar deposits also occur, but these generally do not erode since they are usually located on the inside of bends.

Levees and rip-rap are noted where present and are shown in Atlas B.

The bank composition of the Feather River changes through the study reach. The geologic map shown in the Atlas, shows the relationship between bank composition and the underlying geology. At several locations the composition at the waterline is different from the surficial geology. This commonly occurs when the Laguna formation underlies the Modesto Terrace. The total length and percentage of occurrence of each bank type is shown in Table 6.1-1.

Table 6.1-1. Bank Composition.

BANK COMPOSITION	Linear feet (Both Banks)	Percentage
Bedrock	5425	0.8%
Laguna	33274	4.9%
Modesto	22409	3.3%
Slickens	159938	23.5%
Tailings	65872	9.7%
Flood Plain	96915	14.2%
Alluvial	261098	38.4%
Levee	35861	5.3%

The banks between Oroville and Yuba City are composed of geologic control (older terrace deposits overlying Laguna Formation), cobble mining debris, normal floodplain deposits, or a combination of slickens on the bottom and floodplain deposits on top. The banks of the lower Feather from Yuba City to Verona are composed of either Modesto Formation, or a composite bank of slickens and floodplain deposits

The total length of Modesto and Laguna banks are about 55,000 feet or about 8 percent of the total bank length. Modesto Formation is encountered at RM 54.5 on the left bank, about three miles above Gridley and on the right bank at Gridley. The bank at RM 54.5 is tall and vertical, consists mostly of silt and clay, and appears to be fairly erosion resistant, although some erosion is evident. The Modesto age bank at Gridley has been protected by rock riprap. Although not observed, it is possible that Laguna Formation outcrops along the lower bank below the Modesto.

The Modesto Formation is considered to be geologic control, that is, more resistant to erosion and providing longer term stability with low erosion rates. Where exposed, the Modesto forms light gray, tall, vertical banks. The Modesto banks average about five feet higher than the more recent alluvial banks. Bank undercutting, followed by block failure are the common sequence of events leading up to bank failure in Modesto deposits. The significance of the occurrence of Laguna and Modesto Formation deposits is that the river has not been beyond that point for at least the last 10,000 years or more. Banks with this composition define the extent of the Meander Belt.

Slickens tend to be less erodible than other recent alluvial banks because of the clay content. An analysis by Water Engineering and Technology (1990) of two samples showed an average of 60 percent sand, 18 percent silt, and 22 percent clay. This is a high clay content for an alluvial bank and explains the low erodibility. Below Gridley to Yuba City, reddish-yellow “slickens”, or fine hydraulic mining debris, is exposed in the lower banks in places. The slickens were deposited from about 1856 to 1895 as a result of hydraulic mining of gold-bearing gravel. The slickens consist of fine silt with some clay and tends to be erosion resistant. About 160,000 feet of bank or 23.5 percent was mapped as slickens

Banks composed of recent floodplain deposits overlying slickens are common in the lower river and are mapped as slickens. These banks do not erode quickly because of a stable clay-rich toe. The overlying sand and silt erode by fluvial entrainment or by dry ravel. Sand and gravel point bar deposits with overlying silt and clay floodplain deposits erode in a similar manner, with fluvial entrainment of the point bar deposits, followed by cantilever and block failure of the overlying deposits.

Banks composed of flood plain deposits occur below Gridley and continue downstream to Yuba City. The deposits are dark gray silt and where mapped extend from the toe to the top of the bank. The flood plain deposits were mapped for 97,000 feet or 14 percent of the total bank. In some places, sand and gravel constitutes the lower bank. Flood plain banks are eroding at a fairly rapid rate above and below the confluence with Honcut Creek, at Live Oak, RM 40-42, and at River Mile 34-35. Rip-rap has been added in an attempt to control this erosion just below Honcut Creek and at Live Oak

The dredger tailings are coarse cobble and gravel deposit and are somewhat erosion resistant. The tailings are generally present between Oroville and the lower end of the Wildlife Area above Gridley. Tailings were mapped for 66,000 feet or almost 10 percent of the bank. High flow events, such as the flood of January 1997, cause some channel bed and bank erosion.

However, between River Miles 62 and 59, gravel mining activity has caused multiple shifts in the channel. Numerous ponds dot the area, and may be partially responsible for channel shifts through pond capture. Future bank erosion and channel shifting in this area is mostly dependent on gravel mining activity. Natural bank erosion may also account for some of the river movement in this part of the river.

Below the Thermalito Afterbay outfall, in the high flow reach, the river continues for the most part in the coarse cobble and gravel deposits to Gridley. The cobble banks presently appear stable, with little evidence of major natural erosion or shifts in the channel.

Water Engineering and Technology sampled banks composed of floodplain deposits as part of their geomorphic study of the lower Feather for the USACE. Their grain size analysis results are listed in Table 6.1-2.

Table 6.1-2. Grain Size Analysis Results for Feather River Banks (WET, 1991)

Site Description*	River Mile	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Sorting**
TLB Toe Bank	34.2	.01	.02	.04	2.32
TLB Mid-Bank	34.4	.01	.03	.05	1.99
TLB Mid-Bank	45.0	.04	.07	.12	1.72
TLB Bank Vertical Accretion Fines	45.0	.05	.08	.20	2.11
* TRB = True Right Bank ; TLB = True Left Bank ** $(D_{84}/D_{16})^{1/2}$					

Composite banks are common. These consist of a combination of sediment sizes arranged in layers. The most common are banks composed of slickens in the lower bank, and sand and silt floodplain deposits in the upper bank. The composition of the lower bank generally controls the bank erosion rate. Another bank combination is sand and gravel underlying silt and sand. This type of bank is a product of the normal meandering stream. The sand and gravel was deposited on a point bar. The overlying silt and sand accumulated over time on the floodplain. This type of bank tends to be moderately to highly erodible, depending on the amount of sand in the lower bank. The most erodible banks contain sand in the lower layer.

6.1.2 Bank Protection

Bank protection or rip-rap occurs in many places on the Feather River. Bank protection consists of basalt quarry rock, cobbles, or concrete rubble. Minor bank protection occurs in the low flow section, at the Highway 70 Bridge, just above Robinson Riffle, at the inlet and outlet weirs in the Oroville wildlife area, and at the Thermalito outfall. Between the Thermalito outfall and Honcut Creek rip-rap occurs extensively on both banks near Gridley and down stream, River Miles 51 to 47.5. Over 20,000 feet of rip-rap or 13 percent of the bank is rip-rapped in this 14.7 mile stretch

Between Honcut Creek and Sunset Pumps there is over 10,000 feet of rip-rap. Major areas are the left bank below Honcut Creek, the left bank above and the right bank below the Live Oak launch ramp, and the left bank above the Sunset diversion. Over 18 percent of the bank is rip-rapped in this 5.2 mile stretch.

Between Sunset Pumps and Yuba City 7,250 feet of the right bank but only 250 feet of the left bank is rip-rapped. The riprap occurs mainly on the outside of bends against the levee on the right bank and at bridges. A total of just over 6 percent of the bank is rip-rapped in this 11 mile stretch.

Riprap below Yuba City is common but not extensive. There are over 25,000 feet of rip-rap with most occurring on the left bank along the levee in the lower 7 miles. About 8 percent of the banks are rip-rapped in the 28 mile stretch from Yuba City to Verona.

Overall about 64,000 feet or 10 percent of the banks of the Feather River are rip-rapped. Table 6.1-3 summarizes the extent of riprap for the Feather River from the Thermalito outfall to Verona. Location of riprap is shown on the Feather River Atlas and in the GIS.

Table 6.1-3. Lower Feather River- Rip-Rapped Banks, Oroville to Verona

Table 6.1-3			Rip-rapped Banks Oroville to Verona		
	Outfall to Honcut				
		Rip=Rapped Bank			
		feet	miles	river miles	percent of bank
right bank		14280	2.704545	14.7	18.40%
left bank		6480	1.227273	14.7	8.35%
	Honcut to Sunset Pumps				
right bank		3500	0.662879	5.2	12.75%
left bank		6860	1.299242	5.2	24.99%
	Sunset Pumps to Yuba City				
right bank		7250	1.373106	11	12.48%
left bank		250	0.047348	11	0.43%
	Yuba City to Verona				
right bank		7435	1.408144	28	5.03%
left bank		18310	3.467803	28	12.39%
sum		64365	12.19034	117.8	10.35%

6.1.3 Bank Erosion - Process

Bank erosion varies greatly depending on bank composition. Sand banks are the most erodible, followed by sandy gravel banks. Coarser gravel and cobble banks tend to be more erosion resistant, and erode at relatively slow rates. Banks consisting of clay and silt also erode at slow rates, primarily because of the cohesive nature of clay. The more clay found in the bank, the slower the bank erosion rate. The slickens resulting from hydraulic mining contain abundant clay and subsequently have slow bank erosion rates. Banks composed of the Modesto and Riverbank terrace deposits are stable, but can erode when exposed to high velocity streamflow for long periods of time. In places, the Laguna Formation was observed to underlie the terrace deposits. The terrace deposits are considered to be the edge of the meander belt. Bedrock units are considered non-erodible for this study. Table 6.1-4 shows the estimated erodibility of the geologic units. The erodibility factor used for the Fluvial 12 computer program is also shown.

Table 6.1-4. Estimated Erodibility of Geologic Units

Geologic Unit	* FL-12 Coding	Description of Erosion	Estimated Erosion Rate (feet per 100 years)
Sand Banks	5	extremely erodible	1,000 to 10,000
Composite Silt/Gravel Banks	4	highly erodible	100 to 1,000
Gravel Banks	4	highly erodible	100 to 1,000
Cobbles or Tailings	3	moderately erodible	50 to 100
Clays from Hydraulic Mining ("slickens")	3	moderately erodible	50 to 100
Modesto Formation	3	moderately erodible	50 to 100
Riverbank Formation	2	somewhat erodible	10 to 50
Laguna Formation	1	slightly erodible	1 to 10
Ione Formation	1	slightly erodible	1 to 10
Chico Formation	1	slightly erodible	1 to 10
Mariposa/Logtown Ridge Formation	0	non-erodible	0 to 1
Jurassic Bedrock	0	non-erodible	0 to 1
used in the calibration of the Fluvial-12 sediment transport model (presented in Task 7 -			

Bank erosion occurs on bends and straight reaches. Rates tend to be higher in bends than straight reaches. Bend morphology is such that velocities are higher along the outside, eroding and undercutting the bank. The smaller the radius of curvature, the sharper the bend, and the more erosion occurs. The low sinuosity of the Feather, however, means that there are far more straight banks than curved.

Bank erosion is affected by bank moisture. Dry banks erode at a slower rate, all other factors being equal. Wet banks lose soil cohesion, and the water adds weight. Receding flows after bank full discharge tend to be the most erodible because banks are saturated, positive seepage pressures causing piping and liquefaction, and lack of support and buoyancy from receding flows.

Banks with a uniform composition normally have rotational failures or block failures. These include abandoned channel fills and floodplain deposits consisting mostly of silt and sand. Bank failure processes are similar to that of the lower Sacramento River in that failure modes are highly correlated with bank materials.

Banks with a uniform composition normally have rotational failures or block failures. These include abandoned channel fills and floodplain deposits consisting mostly of silt and sand.

6.1.4 Bank Erosion Site Identification

Bank erosion sites were identified by comparing past and current air photos, survey maps, and field inspection. Banks with noticeable erosion and banks that have eroded in the past have been catalogued

Water Engineering and Technology (1990, 1991) tabulated bank erosion sites between Oroville to Verona. Most of the erosion sites mapped by WET occur along straight sections of stream, mostly because there are more of these. The total length of bank shown as eroding was 18,600 feet for the Yuba City to Verona reach. Several of the sites were noted as alternate bars with erosion occurring as the bars migrated down stream. Because the banks aren't actually eroding we disregarded these sites. Bank erosion rates determined by WET varied from less than one foot to over 26 feet per year.

DWR completed a general description and analysis of erosion sites based on the requirements of the Oroville Facilities FERC relicensing Study Plan G2. Erosion site locations were selected by examining the channel boundaries for the time periods of 1909, 1967 and 2001. Areas displaying obvious channel migration were chosen for further analysis. The sites selected between Oroville and Yuba City included Robinson Riffle (RM 61.7-60.7), MacFarland Riffle (RM 52.3), Herringer Riffle (RM 46.5), Mouth of Honcut Creek (RM 44-45.5), River Mile 35-33.5, and just above the Highway 20 Bridge (RM 28.6). The sites selected between Yuba City and Verona included just upstream of Shanghai Bend (RM26), Shanghai Bend (RM 25), just downstream of Shanghai Bend (RM 24), just below O'Conner Lakes (RM 16), and Nelson Bend (RM 7).

For each site, a general description, a spreadsheet detailing the erosion site calculations, and a map are provided in Appendix C. The general descriptions describe the site location, the maximum erosion rates for both pre- and post-construction of the Oroville Dam (1967), special factors affecting erosion at the site, and the relative accuracy of the photomosaic image correlation. Erosion site calculations are based on the comparison of erosional features as interpreted from surveys and aerial photographs. The maps provide a time sequence series of surveys and images from 1909, 1956 or 1962, 1967, 1986, and 1998 with overlaid line work detailing the erosional cut banks and water's edge at the selected erosion site.

Bank erosion rates were also calculated as part of this study. Pre- and post Oroville Dam meander lines were compiled. Pre- dam erosion and meandering was derived by comparing 1909 and 1965 data. Post dam was measured by comparing 1965, 1986 and 1997 aerial photographs. Bank erosion sites were identified by shifts in bank line, and the average amount of bank recession was measured by using the area and dividing by the bank length. The maximum bank erosion was also measured. The results are detailed in Appendix C and summarized in Table 6.1-5. Bank erosion rates can change because of a number of factors. First, the bank material will change as the river erodes across its meander belt. Second, bend morphology changes with time. Chute cutoffs are the most common of these, resulting in an increase in the radius of curvature. The result is that dramatic shifts in bank erosion loci and rates can occur as a result of these events.

The results from this analysis include calculations of maximum erosion rates and average erosion rates per foot of cut bank. The maximum erosion rate is calculated by measuring the maximum distance between cut banks for two selected photosets, which is then divided by the number of months elapsed between the time the photosets were captured. The resulting number is converted and expressed as feet per year. The average erosion rate per foot of cut bank is calculated by computing the area between cut banks for two selected photosets, dividing this area by the average length of the cut banks, which is then divided by the number of months elapsed between the time the photosets were captured. The resulting number is converted and expressed as acres per foot per year. Pre-dam, 1909-1967, maximum erosion rates ranged from 4 to 19 feet per year while post dam, 1967-1998, erosion rates ranged from 3 to 23 feet per year. A summary of the rates of erosion for each of the sites analyzed is provided in Table 6.1-5. At most of the sites the erosion rate was higher post dam.

Table 6.1-5. Erosion Site Summary Oroville to Yuba City

	Max. width of erosion (ft)	**Rate of Max. erosion (ft/year)**
Erosion Site Analysis at Site 28.6	pre-dam	
	705.3	12.1
	post-dam	
	363.5	11.4
Erosion Site Analysis at Site 33.5	pre-dam	
	224.7	3.9
	post-dam	
	97.0	3.1
Erosion Site Analysis at Site 34.0	pre-dam	
	482.2	8.3
	post-dam	
	743.1	23.4
Erosion Site Analysis at Site	pre-dam	

34.5		
	1,019.9	17.5
	post-dam	
	682.1	21.5
Erosion Site Analysis at Site 35.0	pre-dam	
	1,087.6	18.7
	post-dam	
	277.6	8.7
Erosion Site Analysis at Site 44.0	pre-dam	
	532.8	9.1
	post-dam	
	532.5	16.8
Erosion Site Analysis at Site 44.4	pre-dam	
	319.8	5.5
	post-dam	
	343.9	10.8
Erosion Site Analysis at Site 45.0	pre-dam	
	455.3	7.8
	post-dam	
	420.2	13.2
Erosion Site Analysis at Site 46.4	pre-dam	
	636.9	10.9
	post-dam	
	618.7	19.5
Erosion Site Analysis at Site 52.3	pre-dam	
	566.8	9.7
	post-dam	
	513.6	16.2

6.1.4.1 Shanghai Bend Bank Erosion Site

At Shanghai Bend the Feather River drops over a bedrock shelf of what appears to be Laguna Formation. The river appears to be migrating toward the east across the top of this bedrock surface. During 1909 the main channel was located to the east of the sewage treatment ponds, and there is no mention in the historical literature of problems to steamboat navigation at this site.

Because of the change in channel location it is not possible to do a comparative analysis of erosion at this location. There are three sites in the area that have continued to erode since dam construction. At the bend upstream the right bank has eroded at a maximum average rate of 7.4 ft/yr upstream of a rip-rapped bank. At Shanghai Bend the left bank is eroding at a maximum average rate of 9.5 ft/yr. It is 207 feet to the levee/berm around the sewage treatment pond. At the current rate the pond will be reached in about 25 years. Below Shanghai Bend the right bank is eroding at a maximum average rate of 9.3 ft/yr with 200 ft to the levee.

6.1.4.2 Nelson Bend Bank Erosion Site

At Nelson Bend, RM-7, the Feather River was realigned during 1911 cutting off a large meander loop and focusing the river flow at the bank of the river. A 2,700 ft levee was constructed at this site in 1965 and the site was investigated by DWR in 1967. One of the issues at this site is this is the confluence of the Feather River with the Sutter Bypass and the invert elevation of the Bypass is 15 to 20 below the elevation of the river. There were erosional breakouts through the natural levees that resulted in siltation of crop lands and there were concerns that the river could realign into the Sutter Bypass. The levee has been rocked and the main drop between the Feather and the Sutter bypass has been protected with concrete rubble.

There has been a minor amount of erosion continuing at this location since the construction of the dam. The maximum average rate of erosion has been 3.5 ft/yr.

6.1.5 Select and Monitor Bank Erosion Sites

For selected sites displaying continuing erosion, with some other value such as bank swallow habitat, and with easy accessibility, bank erosion surveys were performed. The surveys included setting survey benchmarks and surveying bank lines using GPS. Re-surveys were performed twice during study to establish bank erosion rates.

6.1.5.1 JEM Farms Bank Erosion Sites (Herringer Riffle)

This summarizes the surveying work that the Engineering Studies Section performed for the Geology Section along the Feather River in the area of J.E.M. Farms in Butte County. The primary purpose of the surveying for this project was to collect enough data so that the current location of the river bank could be accurately mapped. The land surveying for the bank erosion study in Butte County was a combination of both conventional and real-time-kinematic global positioning system (RTK-GPS) survey techniques.

The surveying work for this project had to be of a nature precise enough to ensure subsequent surveys can be done for remapping and analysis of bank erosion, accretion, avulsion, or reliction. To allow for future surveys to be located on the same horizontal datum, it was decided that the North American Datum of 1983 (NAD83) would be used for horizontal control. To establish coordinates for each point, the projection for the

California Coordinate System, Zone 2 (CCS Zone 2 or SPC CA 2), was used. For the vertical datum, the National Geodetic Vertical Datum of 1929 (NGVD29) was used. This is the vertical datum that was used for creation of contour lines on the quad sheets by the United States Geological Survey. For both data, the units used were survey feet (sft).

The primary control point for this survey is from the National Geodetic Survey (NGS). This point is Designation Honcut, Permanent Identifier (PID) KS1035 (see Attachment 1). This point has first order horizontal accuracy and first order, class II, vertical accuracy. Since the elevation listed on the NGS data sheet shows the elevation for the North American Vertical Datum of 1988 (NAVD88), the program CORPSCON was used to convert the elevation to NGVD29. The point was originally measured as a NGVD29 elevation and then converted by NGS to a NAVD88 elevation using CORPSCON; since the procedure was simply reversed to obtain the NGVD29 elevation used in this survey, there is no loss of accuracy.

The GPS survey instruments used were a Trimble 4000SSI receiver at the primary control point and Trimble 4700 receivers at the rovers. These dual-frequency receivers observe carrier phase satellite measurements on both the L1 and L2 frequencies. The base GPS receiver was equipped with a compact L1/L2 antenna. The rover receivers were equipped with micro-centered L1/L2 antennas. All of the antennas were used with ground-planes to greatly reduce the possibility of multi-path problems. The points set using RTK-GPS were located in areas open to the sky to also reduce the chances of problems with multi-path.

After temporary points were established using RTK-GPS, their relative accuracy was verified using a survey control quality Geodimeter 600 series total station. The measured distance between each temporary point was found to be within 0.15 feet horizontally and 0.10 feet vertically of the calculated distance between each point; the calculated distance being based on the coordinates computed from the RTK-GPS. Using these temporary control points along with other points set using the total station, the bank position was mapped by locating every major change in bank alignment along with dozens of supplemental points located between the major changes.

To ensure that future mapping is comparable to this survey, survey monuments were set some distance away from the current bank location. These monuments are #5 rebar set in concrete with aluminum caps stamped “DEPARTMENT OF WATER RESOURCES NORTHERN DISTRICT.” These monuments can be used for control in the future to remap the bank, or can be used as checks if new control is set using GPS or some other method.

An initial survey of the bank lines was performed in November of 2002. The bank lines were resurveyed in March 2004. Figures 6.1-1a and b show the position of the bank lines superimposed on the 1998 digital ortho-photo quarter quads. These data show that between November 2002 and March 2004, with a maximum flow event at the Gridley Gage of 20,000 cfs, erosion continued to occur at these sites at a rate approximately equal to the long term average. Average maximum erosion rates varied from 10 to 30 feet between the two data sets.

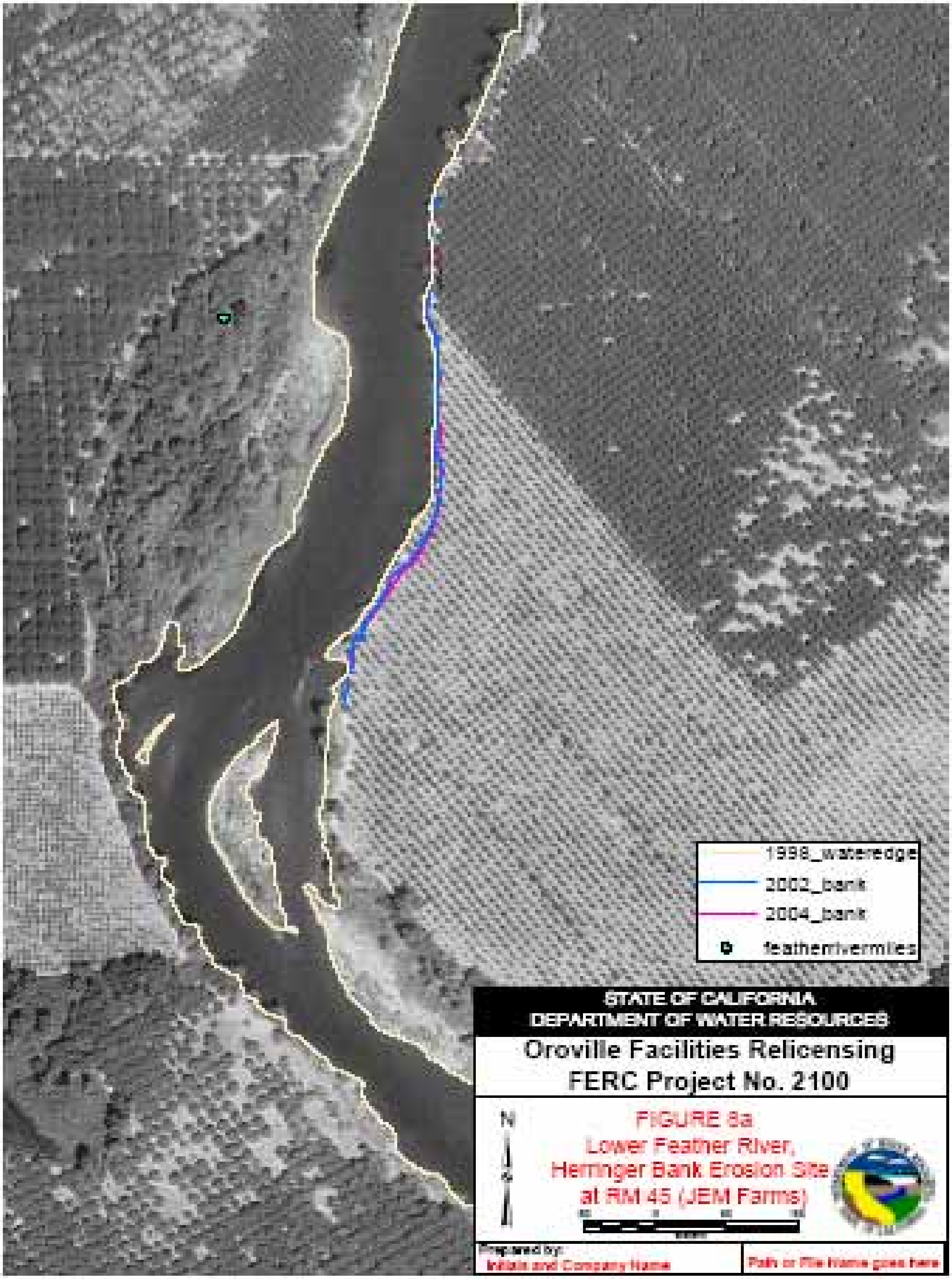

Figure 6.1-13a. Lower Feather River, Herringer Bank Erosion Site at RM 45 (JEM Farms)

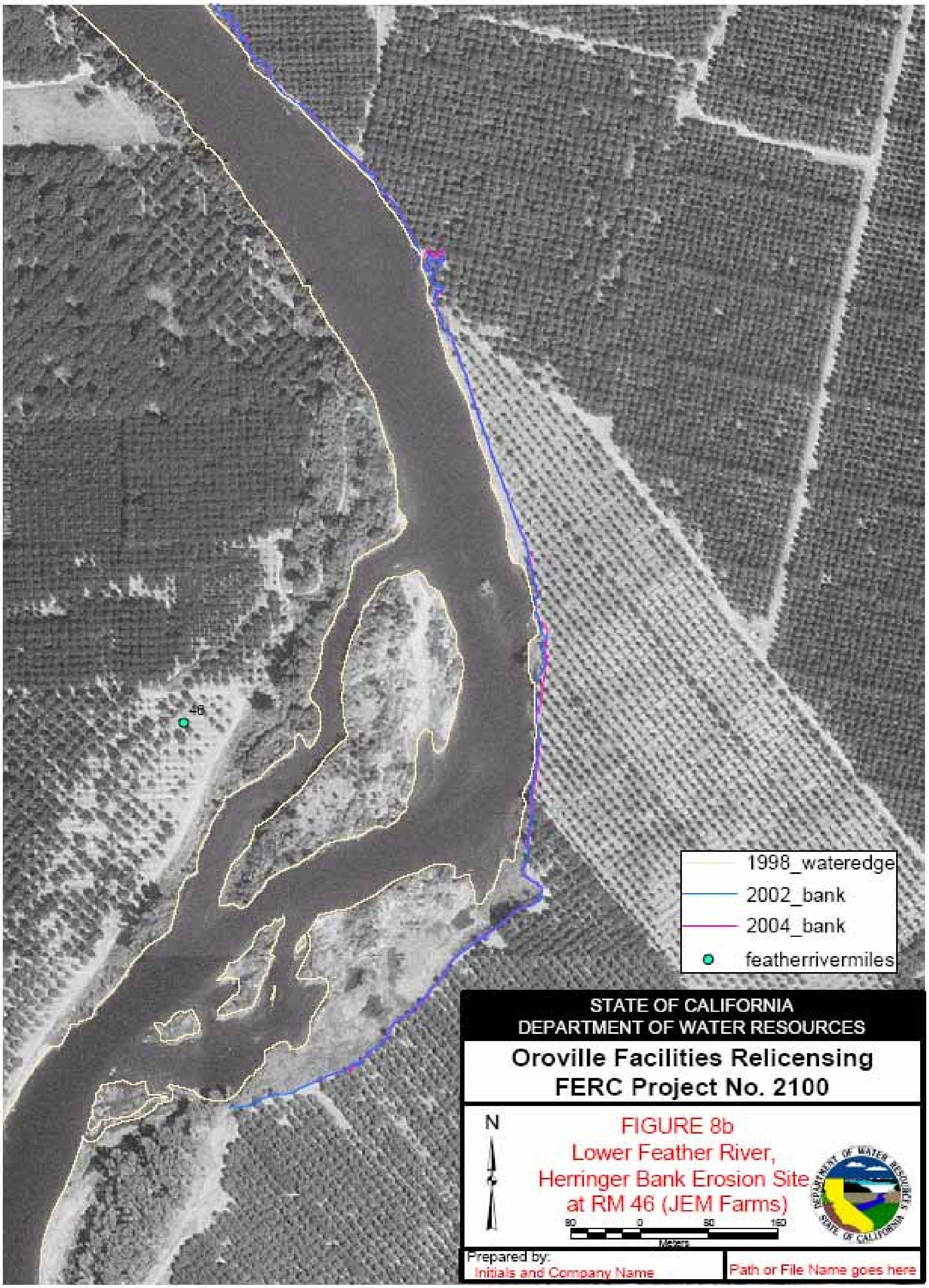

Figure 6.1-1b. Lower Feather River, Herringer Bank Erosion Site at RM 46 (JEM Farms)

7.0 SUMMARY AND CONCLUSIONS

Dams have been documented as causing alterations to riverine environments in areas down steam (see Bibliography). Essentially rivers exist in a dynamic equilibrium that includes flow, flood frequency, sediment load, slope/sinuousity, channel form, and bed characteristics. A dam will alter the primary characteristics of flow volume, flood frequency, and sediment load which then lead to changes in slope/sinuousity, channel form, and bed characteristics.

The Feather River is unique in that prior to the construction of Oroville Dam the river was recovering from the influx of hydraulic mining debris that occurred during 1880 to 1900. It is doubtful that the river had reached an equilibrium state in regards to the vast amount of sediment that had accumulated in the channel (up to 20 feet in places). The superimposition of the dam and subsequent altered hydrology and sediment load on a system that was probably not in equilibrium makes it ,very difficult to assess the alterations caused by the dam versus the ongoing changes occurring as a result of the hydraulic mining debris.

Overall the average rate of channel migration has decreased since dam construction from 2.26 to 1.69 ft./yr. The decreased rate of migration is probably attributable to the decrease in frequency of channel forming flow events. The rate of migration is quite low when compared to the Sacramento River which has migration rates of 6 to 14 ft/yr. The low rate of migration has been attributed to entrenchment of the channel into the slickens deposits of the hydraulic mining debris which are somewhat resistant to erosion.

Even though the overall rate of migration has decreased, a detailed analysis of the sites with the highest erosion indicates that on those sites the rate of erosion has increased since construction of Oroville Dam. Maximum rates of erosion at some sites has increased from 8 to 17 ft/yr to over 20 ft/yr. The bank type at most of these sites is flood plain deposits, silt and sand, which are highly erodible and the maximum rates are found at the outside of meander bends. A possible explanation for the increased erosion rates is that the high summer flows post dam are great enough to erode the toe of the banks on the outside of the meander bends.

8.0 REFERENCES

Allen, Peter M., Jeff Arnold, and Ed Jakubowski. 1999. Prediction of stream channel erosion potential. Environmental and Engineering Geoscience, 5(3). pp 339-351.

Copeland, R.R., D.S. Biedenharn, and J.C. Fischenich. 2000. Channel-forming discharge. United States Army Corps of Engineers. 10pp.

Department of Water Resources. 1994. Sacramento River Bank Erosion Investigation Memorandum Progress Report

El-Shamy, Farouk M. 1977. Environmental impacts of hydroelectric power plants. Journal of the Hydraulics Division. pp.1006-1019

Galay, V.J. 1983. Causes of river bed degradation. American Geophysical Union. Water Resources Research, 19(5). pp.1057-1090

Graf, William L. 1996. Geomorphology and policy for restoration of impounded American Rivers: what is 'natural?'. The Scientific Nature of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology held September 27-29, 1996. John Wiley and Sons Ltd. 473pp.

Jacobson, Robert B., Suzanne R. Femmer, and Rose A. McKenney. 2001. Land-use changes and the physical habitat of streams- a review with emphasis on studies within the United States Geological Survey Federal-State Cooperative Program. United States Geological Survey, United States Department of the Interior. 63pp.

James, L. Allan. 1989. Sustained storage and transport of hydraulic gold mining - sediment in the Bear River, California. Annals of the Association of American Geographers, 79(4). pp. 570-592.

James, Allan. 1999. Time and the persistence of alluvium: river engineering, fluvial geomorphology, and mining sediment in California. Geomorphology 31. Elsevier Science B.V. pp. 265-290.

McManus, Dan. 1989. Bradbury Dam/Lake Cachuma Project. State of California, The Resources Agency. Department of Water Resources. 59pp.

Mount, J. 1995. California Rivers and Streams: The Conflict Between Fluvial Process and Land Use. Berkeley: University of California Press. (For more info: http://www-geology.ucdavis.edu/www/books/rivers.html)

Petts, G.E. 1979. Complex response of river channel morphology subsequent to reservoir construction. Edward Arnold Ltd, 1979. Progress in Physical Geography, 3(3). pp. 329-362

Potyondy, J.P. and E.D. Andrews. 1999. Channel maintenance considerations in hydropower relicensing. Rocky Mountain Research Station. Stream Systems Technology Center. 4pp.

Reports and Papers, Hydrology-Davis. 1938. 7pp.

Sandecki, Michael and Catherine Crossett Avila. 1997. Channel adjustments from instream mining: San Luis Rey River, San Diego County, California. Geological Society of America, Reviews in Engineering Geology, 11. pp. 39-48.

Senate Permanent Fact Finding Committee. The Iron Gate Dam Project- its effect on the Klamath River fisheries. Natural Resources. pp. 179-197.

United States Fish and Wildlife Service. 2000. Impacts of riprapping to ecosystem functioning, lower Sacramento River, California. United States Fish and Wildlife Service, Sacramento, California. 32pp.

United States Geological Survey. 1970. A three-year study of the effects of major impoundments on downstream channel morphology. Project proposal. United States Geological Survey. 4pp.

Warner, Maurice L., John L. Moore, Samar Chatterjee, David C. Cooper, Christopher Ifeadi, William T. Lawhon, and Robert S. Reimers. 1974. An assessment methodology for the environmental impact of water resource projects. Office of Research and Development. United States Environmental Protection Agency, Washington, D.C. pp. 115-119.

Water Engineering & Technology Inc. 1990. Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 78-194) and Feather River (RM 0-28). Prepared for U. S. Army corps of Engineers Sacramento District

Water Engineering & Technology Inc. 1991 Geomorphic Analysis and Bank Protection Alternatives Report for Sacramento River (RM 0-78), Feather River (RM 28-61), Yuba River (RM 0-11), Bear River (RM 0-17), American River (RM 0-23), and portions of Three Mile, Steamboat, Sutter, Miner, Georgiana, Elk and Cache Sloughs. Prepared for U. S. Army corps of Engineers Sacramento District

The following references are listed at:

http://www.amrivers.org/damremovaltoolkit/dambibliography.htm

Church, M. 1995. “Geomorphic response to river flow regulation: Case studies and time-scales.” Regulated Rivers: Research and Management. Vol. 11: 3-22.

Collier, M., R.J. Webb, and J.C. Schmidt. 1996. Dams and Rivers: A Primer on the Downstream Effects of Dams. US Geological Survey, Circular 1126. 94 pp.

Graf, W.L. 1999. “Dam nation: a geographic census of American dams and their large-scale hydrologic impacts.” Water Resources Research. Vol. 35(4): 1305-1311.

Hadley, R.F., W.W. Emmet. 1998. “Channel changes downstream from a dam.” Journal of the American Water Resources Association. 34(3):629-637.

Kondolf, G.M. and M. Larson. 1995. “Historical channel analysis and its application to riparian and aquatic habitat restoration.” Aquatic Conservation: Marine and Freshwater Ecosystems. Vol. 5: 109-126.

Kondolf, G.M. 1997. “Hungry water: Effects of dams and gravel mining on river channels.” Environmental Management. Vol. 21(4): 533-551.

Petts, G.E. 1984. Impounded rivers: perspectives for ecological management. John Wiley and Sons: Chichester, England.

Petts, G.E. 1989. “Perspectives for ecological management of regulated rivers.” Alternatives in Regulated River Management. Gore, J.A. and G.E. Petts (editors). CRC Press, Inc.: Boca Raton, Florida, USA. Pages 3-26.

Power, M.E., W.E. Dietrich, J.C. Finlay. 1996. “Dams and downstream biodiversity: potential food web consequences of hydrologic and geomorphic change.” Environmental Management. Vol. 20(6): 887-895.

Sear, D.A. 1995. “Morphological and sedimentological changes in a gravel-bed river following 12 years of flow regulation for hydropower.” Regulated Rivers: Research and Management. Vol. 10: 247-264.

Williams, D. T. 1977. Effects of Dam Removal: An Approach to Sedimentation. Technical Paper No. 50. U. S. Army Corps of Engineers, The Hydrological Engineering Center.